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ABSTRACT

This volume summarizes the results of a study to assess the relative merits of locating Earth-orbital experiments in either a CSM/Pallet or an AA LEM on early SAA missions. The principal results and conclusions of the study are:

1. With the possible exception of the Pallet's capacity to support a group of "Earth Sensing Applications" experiments, both modules are capable of accommodating an assigned set of representative OSSA experiments.

2. The average time available for S/C modification at KSC is insufficient for both the AA LEM and the CSM/Pallet, the average deficiencies being 21 working days per LEM A/S, 5 working days per LEM D/S, and 14 working days per SM. The overall LEM deficiency is thus 7 working days greater than that of the SM.

3. Payload integration costs, including design, development, fabrication, and installation in flight S/C cannot be said to differ appreciably for the CSM/Pallet and the AA LEM, based on cost information available at this writing. Inclusion of the cost of modifying an Apollo LEM to an AA LEM configuration results in a significant increase in the cost of AA LEM use relative to CSM/Pallet use.

It is concluded that if AA LEM modification costs are excluded from consideration, no clear choice between the modules can be inferred from the areas of support capability, schedules, or costs. The choice then rests on less easily quantifiable considerations, some of which have been discussed in the text.

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SUBJECT: Experiment Support Effectiveness of LEM and CSM for Saturn-Apollo Applications - Case 218

DATE: April 20, 1966

FROM: D. J. Belz

TM-66-1013-2

TECHNICAL MEMORANDUM

INTRODUCTION

This memorandum summarizes the results of a study to determine a preliminary planning basis for selecting mounting locations of experiments to be flown on early Saturn-Apollo Applications missions as defined in the ML-3 Flight Mission Assignment Plan. Specifically, the relative merits of locating Earth orbital experiments in either a CSM containing an Apollo Experiments Pallet or in an Alternate Apollo LEM were considered.

Both spacecraft modules have been evaluated from the standpoint of:

a. physical capability to support a representative set of Earth orbital experiments,

b. modification, checkout, and launch schedules, and

c. development costs.

Results of the study in each of these areas are discussed in the following sections. A brief discussion of less easily quantifiable factors affecting a choice of LEM vs CSM for experiment location is also presented.

SUPPORT CAPABILITY FOR REPRESENTATIVE EXPERIMENTS

The ability of a CSM/Pallet and an AA LEM to support representative sets of experiments has been studied within NASA/MLS and reported in References 1 and 2 which are to be considered companion volumes to the present memorandum. The experiments and experiment groupings for eight early SAA flights were adopted from a compilation prepared within NASA/OSSA (Reference 3); estimates of support requirements for those experiments have previously been made by McDonnell Aircraft and the Martin Co. as Pallet definition study contractors, GAEC as an AAPMPTF support contractor, and IITRI (References 4-8). GAEC estimates generally incorporate data from the IITRI study; otherwise, estimates of support requirements have been arrived at independently by the various contractors cited above. As a result, experiment requirements can often be stated only in terms of a range of estimated values.*

Table 1 summarizes experiment and subsystem support requirements for flights 210 through 214, 218, 219, and 513. Individual experiments included in each experiment group are listed by title in the Appendix together with their required orbital or mission characteristics. Numbers in parentheses are subsystem support requirements charged to experiments. In general, such requirements are different for the two modules primarily because the AA LEM baseline configuration provides most of the needed support whereas the Pallet itself is required to supply subsystem support. Where experiment requirements are stated as a range of estimated values, the maximum total requirement is taken to be the sum of the maximum experiment requirement plus estimated subsystem support values. Numbers preceded by a "greater than" (>) sign are anticipated to be larger than the specified quantities.

Five measures of requirements (and S/C capabilities) have been employed: weight, volume, electrical energy, data return weight, and astronaut time. Other factors of similar importance are not discussed due to the very preliminary state of definition of many experiments considered.

Experiment support capabilities of the CSM/Pallet and AA LEM are listed in Table 2. CSM/Pallet weight, volume, data-return weight, and astronaut time are independent of missions and experiments; electrical energy available is determined by the number of 12 KWH batteries carried on the Pallet and thus varies from flight to flight. AA LEM volume, data return weight, and astronaut time are independent of missions. Weight and electrical energy, however, are variable from flight to flight.

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*In no case, however, should these requirements be interpreted as other than preliminary estimates assumed for purposes of this study.

A comparison of Tables 1 and 2 indicates that:

(a) The AA LEM is capable of supporting all assigned experiments within the limits of its baseline configuration, except on flights 213 and 218 where four additional 50 KWH batteries are required. The addition of such batteries is well within the capability of AA LEM, rendering it entirely suitable as a vehicle for the assigned experiments.

(b) The CSM/Pallet is capable of supporting the assigned experiments with the exception of the "Earth Sensing Applications" group on flight 219. There the weight and volume capability of the Pallet are exceeded. It should be noted, however, that the Pallet is capable of supporting the lower estimate of required weight and volume indicated in Table 1. It can therefore be concluded that the adequacy of the Pallet to support the Earth sensing experiments is questionable; a definitive assessment must await better experiment definition.

It is, of course, possible to conceive of experiment groups that will exceed the support of both CSM/Pallet and AA LEM. However, it has been shown that each module is capable of supporting the experiments assigned in this study, with the qualifications noted above. It should also be noted that the AA LEM is potentially capable of supporting a large class of payloads not suitable for the Pallet, e.g. those requiring pressurized volumes, unpressurized volumes greater than 147 $ft.^3$, and electrical energy greater than 168 KWH.

MODIFICATION, CHECKOUT, AND LAUNCH SCHEDULES

KSC checkout operations for Alternate Apollo spacecraft have been analyzed to estimate the total number of working days required for checkout of each module (Reference 9). Reductions in current Ground Operations Requirements Plan (GORP) schedules were made to eliminate checkout times for systems not required in Alternate Apollo Earth orbital missions, e.g. LEM Ascent Stage propulsion, G&N system, landing gear and landing radar. The checkout time for the Service Module cannot be shortened since all SM systems are retained in Alternate Apollo missions.

The average number of working days between Apollo CSM/LEM delivery dates and ML-3 launch dates is approximately 88 for a CSM and 99 for a LEM. By subtracting estimated checkout times from the average number of days each flight module is available at KSC, an estimate of the number of working days available for S/C modification and primary experiment installation was obtained. It is assumed that experiment checkout on an integrated spacecraft can be accomplished within the time available for basic spacecraft checkout. The results are summarized in Table 3.

Modification times required for Alternate Spacecraft have been estimated by TRW under direction from KSC (Reference 10). Approximate durations required for each module are:

LEM A/S	52 working days
LEM D/S	35 working days
SM	18 working days

The average time available for modification at KSC is therefore insufficient for both LEM and CSM, the average deficiency being 21 working days per LEM A/S, five working days per LEM D/S, and fourteen working days per SM. The overall LEM deficiency is thus seven working days greater than that of the SM.

COST COMPARISON

This section is primarily concerned with costs arising from design, development, fabrication, and installation of experiments into a CSM/Pallet or Alternate Apollo LEM.

LEM costs are based on estimates prepared by GAEC as reported in References 11 and 12; those associated with the CSM/Pallet are as stated in Reference 1, which presents cost estimates based on verbal communications with representatives of NASA/MSC, North American Aviation, and the Apollo Experiments Pallet definition study contractors.

Nonrecurring and recurring costs attributable to integration and installation of experiments into an AA LEM are shown in Table 4; following the GAEC convention, nonrecurring costs are assigned to the first flight in which such costs are incurred. Activities listed in Table 4 include the following:

1. Design engineering - definition of subsystem capabilities; design and test of compatibility equipment to provide an interface between experiment and spacecraft.

2. Support engineering - design, development, and procurement of GSE to checkout installed experiments and compatibility equipment.

3. Tooling - associated with fabrication and installation of experiment compatibility equipment.

4. Production - fabrication of hardware for above activities (includes GSE fabrication). Experiment installation at KSC is included under production tasks.

Cost estimates associated with the integration of experiments into an Apollo Pallet and integration of the Pallet into a CSM are expected to be available from the Pallet definition study contractors and North American Aviation before the end of April 1966. In the interim, Pallet cost estimates presented in Reference 1 are used as a basis for this study. Such figures are not as detailed as those quoted above for the AA LEM nor are they anticipated to be anything other than rough approximations.

Nonrecurring costs shown in Table 5 are based on a total of five flight pallets; it is not anticipated that these will be significantly perturbed by an increase or decrease of one in the number of flight articles planned. It is thus possible to compare nonrecurring CSM/Pallet costs shown in Table 5 with those for the AA LEM (Table 4). This comparison is illustrated in Table 6. Recurring costs are shown as average costs per flight article.

Some development costs previously associated with the integration of M&SS cameras in SM Sector I may be attributable to Pallet integration since the OMSF decision not to fly M&SS cameras in Sector I of the SM. Such costs have not, however, been included in this comparison. AA LEM costs shown do not include the modification of an Apollo LEM to an Alternate Apollo LEM configuration.*

Table 6 indicates that, given an Apollo CSM and an Alternate Apollo LEM, it is more costly to fly experiments using a CSM/Pallet configuration than an AA LEM. The significance of this indication is questionable, however, in view of the very approximate nature of the CSM/Pallet

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*Such costs have been estimated by GAEC and MSC to be approximately $\$50 \times 10^6$ nonrecurring and $\$5 \times 10^6$/flight recurring, exclusive of the costs of crew training and mission simulation.

costs available. The nonrecurring costs, which differ by 4.2%, are, for practical purposes, indistinguishable.

CSM/Pallet recurring costs are 31.6% higher than average AA LEM recurring costs. Recurring costs therefore do or do not differ appreciably depending on whether it is assumed that the sum of the percentage errors in each estimate is less than or greater than 31.6%. For example, a ±16% error in each recurring cost estimate is sufficient to reverse the conclusion that CSM/Pallet recurring costs are greater than those for the AA LEM.

It is therefore concluded that payload integration costs, including design, development, fabrication, and installation, cannot be said to differ appreciably for the CSM/Pallet and the AA LEM, based on cost information available at this writing.

GENERAL CONSIDERATIONS

The relative merits of an AA LEM or CSM/Pallet for Alternate Apollo experiment support are dependent on several general considerations in addition to those discussed above. A number of these are summarized in this section.

1. CSM/Pallet Advantages - Availability of a Pallet would:

   (a) permit "CSM only" flights,

   (b) provide a means of achieving at least partial mission success on off-nominal dual launch flights in which the CSM-LEM rendezvous is not actually accomplished, and

   (c) provide a capability for CSM lifetime extension by loading the Pallet with batteries, GOX, LiOH, etc.

Payload integration activities can be performed with a flight-article Pallet earlier than a flight-article LEM. In addition, it may be possible to mount a Pallet on the LEM D/S or on an SIV-B Spent Stage Experiment Support Module.

2. CSM/Pallet Disadvantages - Unless adjacent RCS thrusters are disabled, thruster plumes impinging on experiment sensors may degrade the quality of experimental data. Similarly, wastes released from the CM may also degrade experiments by impinging on sensors. On missions where the "barbeque roll" mode of CSM thermal control is employed, SC rotation may interfere with the acquisition of data for

some experiments.* Astronaut access to experiments for setup and data retrieval requires EVA. The radioactive propellant gauging system on the SM RCS may induce film fogging and excessive background radiation unless a weight penalty is paid for shielding.

3. LEM Advantages - Astronaut access to experiment equipment within the A/S pressurized volume can be performed without EVA. The orbital storage potential of LEM's will, if developed, provide a capability to reuse costly equipment and perform studies of long duration space effects on equipment. Development of the Alternate Apollo LEM provides a stepping stone to the more extensive capabilities of the follow-on LEM Lab configuration.

4. LEM Disadvantages - Assignment of bioscience experiments to dual launch missions in which the LEM is launched first necessitates orbital storage of biological specimens. Use of the AA LEM on S-IB flights requires dual launch and rendezvous where use of the CSM/Pallet requires only one launch vehicle. If costs of developing an alternate Apollo LEM from an Apollo LEM are included, LEM flights are more expensive than CSM/Pallet flights.

CONCLUSIONS

The representative earth orbital experiments considered in this study can, with the qualifications noted above, be flown on the assigned flights. In general, the additional capability of the LEM is somewhat greater than that of the Pallet.

A consideration of launch schedules and modification times indicates a deficiency of time available for KSC modifications for both modules, the LEM deficiency being seven working days greater than that of the SM.

Current estimates of costs indicate no significant difference in payload integration activities for the two modules; inclusion of the cost of modifying an Apollo LEM to an AA LEM configuration results in a significant increase in the cost of LEM use relative to CSM/Pallet use.

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*This is not a problem on the LEM if experiments are properly gimballed.

It is therefore concluded that if AA LEM modification costs are excluded from consideration, no clear choice between the modules can be inferred from the areas of support capability schedules or costs considered above. The choice then rests on less easily quantifiable considerations, some of which have been listed in the preceding section.

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Attachments
Tables 1 through 6
Appendix

TABLE 1 - EXPERIMENT AND SUPPORT REQUIREMENTS FOR FLIGHTS 210 - 214, 218, 219, AND 513

	EXPERIMENT GROUPS	WEIGHT (LBS)		VOLUME (FT.^{3})		ELECTRICAL ENERGY (KWH)		DATA RETURN WEIGHT (LBS)	ASTRONAUT TIME (MAN-HOURS)
		EXPT. RQMTS. (SUPPORT RQMTS)	MAX. TOTAL RQMT.	EXPT. RQMTS. (SUPPORT RQMTS)	MAX. TOTAL RQMT.	EXPT. RQMTS. (SUPPORT RQMTS)	MAX. TOTAL RQMT.		
210 CSM/PALLET	1) INTERDISCIPLINARY EXPERIMENTS 2) METEOROLOGICAL APPLICATIONS	1279. (2975.)	4254.	105.5 (39.1)	144.6	46.8 (30.5)	77.3	>142.	141.
211 CSM/PALLET	SOLAR ASTRONOMY (ATM VERIFICATION)	876. TO 1292. (1650.)	2942.	43. TO 128. (15.3)	143.3	3. TO 10.25 (27.35)	37.6	22. TO > 58.	32. TO > 57.
212 AA LEM	1) INTERDISCIPLINARY EXPERIMENTS 2) SOLAR ASTRONOMY (ATM VERIFICATION)	2377. TO 4525. (536)	5061.	94. TO 232. (-)	232.	8. TO 42. (47.)	89	101. TO > 177.	56. TO > 95.
213 AA LEM	1) METEOROLOGICAL APPLICATIONS 2) BIOSCIENCE	832. TO 1160. (887)	2047.	35. TO 77. (-)	77.	28. TO 103. (45)	148.	220 TO > 235.	>143.
214 CSM/PALLET	BIOSCIENCE	664. (3250.)	3914.	99.5 (47.0)	146.5	88.0 (31.6)	119.6	212.	25.
218 AA LEM	EARTH SENSING APPLICATIONS	856. TO 2224. (990.)	3214.	45. TO 61. (-)	61.	20. TO 101.45 (50.85)	152.3	140. TO > 472.	4. TO > 42.
219 CSM/PALLET	EARTH SENSING APPLICATIONS	856. TO 2224. (4300.)	6524.	45. TO 99.6 (59.5)	159.1	20. TO 101.45 (50.85)	152.3	140. TO > 472.	4. TO > 42.
513 CSM/PALLET AA LEM	SOLAR ASTRONOMY (ATM; OPERATIONAL EXPERIMENTS)	CSM/PALLET 876. TO 1292. (1650.)	2942.	CSM/PALLET 43. TO 128. (15.3)	143.3	CSM/PALLET 3. TO 10.25 (27.35)	37.6	CSM/PALLET 22. TO>58.	CSM/PALLET 32. TO>57.
		AA LEM 876. TO 1292. (150)	1442.	AA LEM 43. TO 64. (-)	64.	AA LEM 3. TO 10.25 (27.35)	37.6	AA LEM 22. TO > 58.	AA LEM 32. TO > 57.

TABLE 2 - CSM/PALLET AND AA LEM EXPERIMENT SUPPORT CAPABILITIES

FLIGHT NO. & S/C CONFIGURATION		WEIGHT (LBS.)	VOLUME (FT.^{3})	ELECTRICAL ENERGY (KWH)
210 CSM/PALLET		5000.	147.	84. (SEVEN 12 KWH) BATTERIES)
211 CSM/PALLET		5000.	147.	48. (FOUR 12 KWH BATTERIES)
212 AA LEM		14,576.	17.5 PRESSURIZED 1700. UNPRESSURIZED	121.
213 AA LEM		6,534.	17.5 PRESSURIZED 1700. UNPRESSURIZED	324. (50. KWH BATTERIES ADDED TO AA LEM BASELINE CONFIGURATION)
214 CSM/PALLET		5000.	147.	120. (TEN 12 KWH BATTERIES)
218 AA LEM		6,534.	17.5 PRESSURIZED 1700. UNPRESSURIZED	324. (50. KWH BATTERIES ADDED TO AA LEM BASELINE CONFIGURATION)
219 CSM/PALLET		5000.	147.	156. (THIRTEEN 12 KWH BATTERIES)
513	CSM/ PALLET	5000.	147.	48. (FOUR 12 KWH BATTERIES)
	AA LEM	2458.	17.5 PRESSURIZED 1700. UNPRESSURIZED	91.

NOTES: 1. DATA RETURN-WEIGHT CAPABILITY IS 500# FOR EACH MISSION.

2. ASTRONAUT TIME AVAILABLE IS 340 MAN-HOURS PER MISSION.

TABLE 3 - AVERAGE MODIFICATION AND CHECKOUT TIME AVAILABLE AT KSC FOR ALTERNATE APOLLO FLIGHTS

MODULE	MODIFICATION TIME		CHECKOUT TIME	
	WORKING DAYS*	CALENDAR MONTHS+	WORKING DAYS*	CALENDAR MONTHS+
SM	4	0.184	84	3.87
LEM A/S	31	1.43	68	3.13
LEM D/S	30	1.38	69	3.18

REQUIRED MODIFICATION TIMES IN WORKING DAYS:

LEM A/S	52
LEM D/S	35
SM	18

*ASSUMES TWO SHIFTS PER WORKING DAY.

+ASSUMES FIVE WORKING DAYS PER WEEK.

TABLE 4 - COSTS OF INTEGRATION AND INSTALLATION OF EXPERIMENTS INTO FOUR ALTERNATE APOLLO LEMS*

ACTIVITIES	FLIGHT				ACTIVITIES TOTALS
	212	213	513	218	
NONRECURRING					
DESIGN & DEVELOPMENT	5.12	2.65	0.94	2.93	11.64
SUPPORT	1.42	1.10	0.31	1.10	3.93
TOOLING	0.19	0.24	0.06	0.25	0.74
FLIGHT SUBTOTALS	6.73	3.99	1.31	4.28	16.31+
RECURRING					
PRODUCTION	1.17	1.38	0.75	1.43	4.73
SPARES	0.57	0.57	0.14	0.60	1.88
PROGRAM PLANNING AND MANAGEMENT	0.36	0.33	0.05	0.27	1.01
FLIGHT SUBTOTALS	2.10	2.28	0.94	2.30	7.62++
FLIGHT TOTAL	8.83	6.27	2.25	6.58	23.93+++

*ALL FIGURES ARE IN MILLIONS OF DOLLARS.

+NONRECURRING COST TOTAL

++RECURRING COST TOTAL

+++GRAND TOTAL FOR FLIGHTS 212, 213, 218, AND 513.

TABLE 5 - COSTS OF INTEGRATION AND INSTALLATION OF EXPERIMENTS AND PALLET INTO AN APOLLO CSM

	NONRECURRING COSTS	RECURRING COSTS PER FLIGHT
EXPERIMENT/PALLET INTEGRATION AND INSTALLATION	12.	2.
PALLET/CSM INTEGRATION AND INSTALLATION	5.	0.5
TOTAL	17.	2.5

NOTE: TOTAL OF NONRECURRING AND RECURRING COSTS FOR ML-3 FLIGHTS CONSIDERED IS 29.5 MILLION DOLLARS FOR FIVE PALLET FLIGHTS VS 23.9 MILLION DOLLARS FOR FOUR AA LEM FLIGHTS.

TABLE 6 - COMPARISON OF AA LEM AND CSM/PALLET COSTS

	CSM/PALLET	AA LEM
NONRECURRING COSTS	17.	16.3
RECURRING COSTS PER FLIGHT	2.5	1.9

NOTE: ALL FIGURES ARE IN MILLIONS OF DOLLARS.

APPENDIX

EXPERIMENT/MISSION CATEGORIES

1. Meteorological Applications

   Orbital parameters: 90° inclination; 120-200 NM altitude

   Experiments:

   Millimeter Wave Propagation
   Measurement of Backscatter Radiation in Near IR
   Dielectric Tape Camera
   Polarization Measurements
   Atmospheric Iodine
   IR Temperature Sounding

2. Bioscience

   Orbital Parameters: 28.5° inclination; 120-200 NM altitude

   Experiments:

   Aeronomy and Wake Physics
   Metabolism and Physiology
   Frog Otolith Functions

3. Earth Sensing Applications

   Orbital Parameters: 90° inclination; 120-200 NM altitude

   Experiments:

   Measurements of Backscatter Radiation in Near IR
   Polarization Measurements
   Gravity Gradient
   Magnetometer
   Microwave Spectrometer
   Stellar Refraction Pressure Measurement
   Multispectral Photography
   Laser Altimeter and Support Camera
   Side Looking Radar (8Gc)
   Navigation and traffic Control.

4a. Solar Astronomy (ATM Verification)

Orbital Parameters: 28.5° inclination; 120-200 NM altitude

Experiments:

Apollo Telescope Mount (ATM) Test
White Light Coronagraph
High Resolution X-ray Telescope
UV Spectrograph/Spectroheliograph
UV Spectrometer

4b. Solar Astronomy (ATM; operational experiments)

Orbital Parameters: 28.5° inclination; synchronous altitude

Experiments:

Apollo Telescope Mount (ATM) Utilization
White Light Coronagraph
High Resolution X-ray Telescope
UV Spectrograph/Spectroheliograph
UV Spectrometer

5. Interdisciplinary Experiments

Orbital Parameters: 28.5° inclination; 120-200 NM altitude

Experiments:

Aeronomy and Wake Physics
X-ray Astronomy
Nuclear Emulsion
Sky Mapping (UV).

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